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# Designing with Soil: Development and Use of a Wastewater Hydraulic Linear and Infiltration Loading Rate Table


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## ABSTRACT

Wastewater infiltration loading rates are estimated based on the wastewater quality and soil characteristics related to soil pores. Hydraulic linear loading rates are estimated based on soil characteristics related to soil pores and to the depth and slope of horizontally moving water. A table to derive design wastewater infiltration and hydraulic linear loading rates from field determined soil and site characteristics is used for soils with vertical flow restricting horizons. Wastewater infiltration systems installed in soils with vertical flow restricting horizons in Lake County, Ohio were recently found to be failing at an unacceptable rate. County Health District staff studied potential designs and soil and site evaluation procedures. As a result of these efforts successful experimental systems have been installed using soil and site information to estimate the design infiltration rate and hydraulic linear loading rate.


## INTRODUCTION

The rate wastewater infiltrates soil from wastewater infiltration systems is limited by clogging layers and controlled by the nature of both the clogging layer and the soil. Once in the soil the added water must continue to move away from the infiltration surface. This flow is independent of the nature of the clogging layer and only dependent on the nature of the soil. In a free draining soil the water moves away from the system following the water potential gradients and at usual wastewater loading rates the soil water moves downward. In soils with flow restrictions water movement may become horizontal. Estimated horizontal soil water movement must be greater than the infiltration rate for the system to function hydraulically. If the infiltration rate exceeds the horizontal flow the soil will saturate and water will come to the ground surface.

There are many regions, including some areas of Lake County, Ohio, with soils having shallow flow restricting horizons. Although these horizons present difficult hydraulic design problems the flow restricting horizon protects the groundwater. These soils have difficulty dissipating water from winter snow melt and spring rains. During this period of the year the water remains above the restricting horizons, sometimes saturating the surface horizons. Hydraulic system failures have been prevalent from trenches in these soils. To successfully estimate infiltration or wastewater loading rates and horizontal water movement a field practitioner needs a method to translate field described characteristics to estimated design values. Based on the site evaluation and the design values, appropriate wastewater treatment designs are selected.

### Paper Objectives

1. Present a table to estimate wastewater infiltration and hydraulic linear loading rates based on soil characteristics and assuming a wastewater quality and volume and
2. Demonstrate the application and use of a table for estimating loading rates in Lake County, Ohio as part of an improvement plan.

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## Wastewater Infiltration or Loading

Wastewater infiltration or loading rates define the rate wastewater enters the soil. When applying septic tank effluent a clogging layer forms at the infiltrative surface. Clogging layers impede water infiltration and reduce the loading applied to far below the maximum infiltration rate of unclogged soil. Wastewater loading rates to clogged soil have been measured by Keys, et al, (1998). They found that actual clogged soil infiltration rates in sandy soil are much less than those estimated for design.

Wastewater infiltration into soil is dependent on the character of both the clogging and soil. Since soil is a factor in infiltration rate through a clogging layer, wastewater loading rates will vary from soil to soil with the same clogging. The differences in wastewater infiltration rates are related to soil characteristics defining pore sizes and pore size distribution. Texture, structure and consistence each contribute information about soil pores. Also, the mineralogy of the clay fraction is important. Of the soil characteristics soil structure provides the most information.

Commonly described soil characteristics can be used with knowledge of operating clogged systems to estimate design values for wastewater infiltration for different soils assuming standard domestic wastewater and design volumes of 150 gpd/bedroom or greater. Design safety factors are built into wastewater volumes and therefore design values for infiltration into soil are higher than actual. A method for predicting loading rates for domestic septic tank effluent based on soil morphological descriptions and wastewater volumes for domestic wastewater for 150 gal/day/bedroom was developed (Tyler, et al., 1991).

In the absence of soil clogging, as is likely when applying wastewaters of reduced organic strength wastewater, infiltration rates are higher than for clogged soil. The increase in loading rate is much greater for soil with larger pores than for those with fine pores. For example, sandy soil loading rates are much greater without clogging than clogged sandy soil rates while in clayey soils the loading rate difference is small. As with loading rates for clogged soil, loading rates for soil receiving wastewater of low organic strength are related to the pores and therefore the described soil morphology. A method for predicting loading rates for wastewaters of reduced organic strength wastewater based on soil morphological descriptions has been reported (Tyler and Converse, 1994)

## Water Percolation and Hydraulic Linear Loading Rate

Once through the clogging layer and in the soil, wastewater moves in the same way any soil water moves. In a free draining soil in a humid environment or for infiltration systems of sufficient volume water will flow predominantly downward. Downward moving water reaching a horizon of lower permeability than the rate of precipitation or precipitation plus added wastewater will saturate. Some of the saturated zone water will continue downward movement but much will move horizontally down hill through more permeable shallow horizons. The steeper the slope the faster the water moves. If horizons are perfectly level then the water will build a mound beneath the infiltration surface and the groundwater surface created by the mound becomes the hill to drive the horizontal water movement.

Horizontally moving water will move in the zone equal to the distance from the base of the infiltration system to the flow restriction. This distance is the infiltration distance and is the same as the stand off or separation distance referred to in regulations for treatment of wastewater. The soil depth of the infiltration distance must continue down the slope. If shallower horizons exist downslope the entire soil will saturate and the system will fail. The goal is to keep all of the water below the ground surface to provide treatment by the soil and protect against human contact. The thicker the infiltration distance the more water movement possible.

The horizontal flow is also dependent on the ability of the soil to move the water horizontally. This is known as saturated horizontal hydraulic conductivity. Saturated hydraulic conductivity is related to soil pore sizes and to the field described soil characteristics utilized to determine wastewater infiltration or loading rates. The more permeable the soil the greater the horizontal flow.

The estimated horizontal flow capacity, in excess of the natural flow, is the hydraulic linear loading rate for the design of the system. Hydraulic linear loading rate or the volume of wastewater the landscape can accept per unit length of system per unit of time was first defined by Tyler and Converse, 1984. Hydraulic linear loading rate is estimated from the field determined slope, horizon thickness and described soil morphology. Hydraulic linear loading rates may not be limiting to the design of some wastewater infiltration systems. Hydraulic linear loading rate is only limiting if there is a vertical flow restricting horizon below the infiltration surface. In some situations oxygen supply may be limiting.

For design, the infiltration system length is the design wastewater volume divided by the hydraulic linear loading rate. The width of the infiltration component is hydraulic linear loading rate divided by the wastewater infiltration rate. Therefore, for design, values of hydraulic linear loading rate and wastewater infiltration must be estimated.

Table 1 is for estimating wastewater infiltration into soil for septic tank effluent with BOD >30 mg/L or low organic strength wastewater of BOD <30 mg/L and hydraulic linear loading rates based on field described soil and site characteristics of texture, structure, consistence, horizon thickness, and slope. The table is used only for soil horizons of very firm or weaker consistence and is not intended for soils of smectitic mineralogy. All characteristics needed for table use are determined during the soil and site evaluation by a soil scientist.

Texture and structure are in columns along the left side of the table and reported as abbreviations. Abbreviations are nationally accepted soil science abbreviations of the Natural Resource Conservation Service of the United States Department of Agriculture (Schoeneberger, P.J, et al., 1998). Because soil characteristics of texture and structure are used to determine both wastewater infiltration and hydraulic linear loading rates only one table is needed.

Slope and infiltration distance for wastewater transmission are across the top of the table. Slope is the slope of the top of the flow-restricting horizon, which in many soil settings is also the slope of the ground surface. This value must be measured for the area proposed for wastewater infiltration. The infiltration distance is the vertical distance from the bottom of the infiltration surface to the top of the limiting layer. Infiltration distance may be one horizon, a portion of a horizon or portions of several horizons. The distance must be confirmed to be available downslope to confirm wastewater will remain below ground.

Values for infiltration loading rates and for hydraulic linear loading rates are estimates based primarily on experience. The logic and trends in values presented fit with the scientific basis and with experience. Further research and testing is needed to verify the values. Hydraulic linear loading rates are for domestic wastewaters assuming 150 gpd/bedroom. The design safety factor is imbedded in the design wastewater flow. Designers using actual wastewater flow rates should assume the table values for wastewater infiltration to be more than three times higher than should be used when using actual flows.

For infiltration loading rate for wastewater of BOD >30 mg/L, Table 1 column D, the loading rates decrease as soil texture gets finer or going down the table. Also, within a texture grouping the loading rates increase as structure shape goes from massive to prismatic, blocky and granular. For any structure shape within a texture group infiltration loading rate increases as structure gets stronger. Therefore, moderate and strong structure, abbreviations 2, 3 have higher loading rates. There are similar trends in infiltration loading rates for wastewater of BOD <30 mg/L, column E, but the rates are higher than for the higher strength wastewater.

Hydraulic linear loading rates increase from the lower left corner of the table, column F row 27, to the upper right, column N row 1 and range from 2 to 8 gal/da/ft. For a given soil texture and structure combination the hydraulic linear loading rate increases as the slope class increases. Also, for a given soil texture and structure combination and slope class the hydraulic linear loading rate increases as the infiltration distance increases.

Assume a soil with a horizon 36 inches deep consisting of silt loam, SIL; with medium, moderate subangular blocky structure, m2sbk; friable consistence and not smectitic over a very slowly permeable horizon. The slope is 8%. Assume the system infiltration surface is at the ground surface. From Table 1 values of infiltration loading rate and hydraulic linear loading rate corresponding to this soil are found in row 19. The infiltration rate of wastewater with BOD >30 mg/L is 0.6 gal/da/ft2 and for wastewater of BOD <30 mg/L it is 0.8 ga;/da/ft$^2$. The linear loading rate from column K row 19 is 4.0 gal/da/ft and corresponds to a slope 8% and an infiltration distance of 36 inches.

Table 1. Infiltration rates in gal/da/ft$^2$ for wastewater of >30 mg L$^{-1}$ or wastewater of <30 mg L$^{-1}$ and hydraulic linear loading rates in gal/da/ft for soil characteristics of texture and structure and site conditions of slope and infiltration distance. Values assume wastewater volume of >150 gal/da/bedroom. If horizon consistence is stronger than firm or any cemented class or the clay mineralogy is smectitic, the horizon is limiting regardless of other soil characteristics

| | | | | | Hydraulic Linear Loading Rate, gal/da/ft | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Slope | | | | | | | | | |
| | | | | | 0-4% | | | 5-9% | | | >10% | | | |
| Soil Characteristics | | | Infiltration Loading Rate, gal/da/ft$^2$ | | Infiltration Distance, in. | | | Infiltration Distance, in. | | | Infiltration Distance, in. | | | |
| Texture | Structure | | | | | | | | | | | | | |
| | Shape | Grade | >30 mg/L | <30 mg/L | 8-12 | 12-24 | 24-48 | 8-12 | 12-24 | 24-48 | 8-12 | 12-24 | 24-48 | Row |
| COS, S, LCOS, LS | -- | 0SG | 0.8 | 1.6 | 4.0 | 5.0 | 6.0 | 5.0 | 6.0 | 7.0 | 6.0 | 7.0 | 8.0 | 1 |
| FS, VFS,LFS,LVFS | -- | 0SG | 0.4 | 1.0 | 3.5 | 4.5 | 5.5 | 4.0 | 5.0 | 6.0 | 5.0 | 6.0 | 7.0 | 2 |
| CSL, SL | -- | 0M | 0.2 | 0.6 | 3.0 | 3.5 | 4.0 | 3.6 | 4.1 | 4.6 | 5.0 | 6.0 | 7.0 | 3 |
| | PL | 1 | 0.2 | 0.5 | 3.0 | 3.5 | 4.0 | 3.6 | 4.1 | 4.6 | 4.0 | 5.0 | 6.0 | 4 |
| | | 2, 3 | 0.0 | 0.0 | - | - | - | - | - | - | - | - | - | 5 |
| | PR/BK /GR | 1 | 0.4 | 0.7 | 3.5 | 4.5 | 5.5 | 4.0 | 5.0 | 6.0 | 5.0 | 6.0 | 7.0 | 6 |
| | | 2,3 | 0.6 | 1.0 | 3.5 | 4.5 | 5.5 | 4.0 | 5.0 | 6.0 | 5.0 | 6.0 | 7.0 | 7 |
| FSL, VFSL | -- | 0M | 0.2 | 0.5 | 2.0 | 2.3 | 2.6 | 2.4 | 2.7 | 3.0 | 2.7 | 3.2 | 3.7 | 8 |
| | PL | 1,2,3 | 0.0 | 0.0 | - | - | - | - | - | - | - | - | - | 9 |
| | PR/BK /GR | 1 | 0.2 | 0.6 | 3.0 | 3.5 | 4.0 | 3.3 | 3.8 | 4.3 | 3.6 | 4.1 | 4.6 | 10 |
| | | 2,3 | 0.4 | 0.8 | 3.3 | 3.8 | 4.3 | 3.6 | 4.1 | 4.6 | 3.9 | 4.4 | 4.9 | 11 |
| L | -- | 0M | 0.2 | 0.5 | 2.0 | 2.3 | 2.6 | 2.4 | 2.7 | 3.0 | 2.7 | 3.2 | 3.7 | 12 |
| | PL | 1,2, 3 | 0.0 | 0.0 | - | - | - | - | - | - | - | - | - | 13 |
| | PR/BK /GR | 1 | 0.4 | 0.6 | 3.0 | 3.5 | 4.0 | 3.3 | 3.8 | 4.3 | 3.6 | 4.1 | 4.6 | 14 |
| | | 2, 3 | 0.6 | 0.8 | 3.3 | 3.8 | 4.3 | 3.6 | 4.1 | 4.6 | 3.9 | 4.4 | 4.9 | 15 |
| SIL | -- | 0M | 0.0 | 0.2 | 2.0 | 2.5 | 3.0 | 2.2 | 2.7 | 3.2 | 2.4 | 2.9 | 3.4 | 16 |
| | PL | 1,2,3 | 0.0 | 0.0 | - | - | - | - | - | - | - | - | - | 17 |
| | PR/BK /GR | 1 | 0.4 | 0.6 | 2.4 | 2.7 | 3.0 | 2.7 | 3.0 | 3.3 | 3.0 | 3.5 | 4.0 | 18 |
| | | 2,3 | 0.6 | 0.8 | 2.7 | 3.0 | 3.3 | 3.0 | 3.5 | 4.0 | 3.3 | 3.8 | 4.3 | 19 |
| SCL,CL SICL | -- | 0M | 0.0 | 0.0 | - | - | - | - | - | - | - | - | - | 20 |
| | PL | 1,2,3 | 0.0 | 0.0 | - | - | - | - | - | - | - | - | - | 21 |
| | PR/BK /GR | 1 | 0.2 | 0.3 | 2.0 | 2.5 | 3.0 | 2.2 | 2.7 | 3.2 | 2.4 | 2.9 | 3.4 | 22 |
| | | 2,3 | 0.4 | 0.6 | 2.4 | 2.9 | 3.4 | 2.7 | 3.0 | 3.3 | 3.0 | 3.5 | 4.0 | 23 |
| SC, C, SIC | -- | 0M | 0.0 | 0.0 | - | - | - | - | - | - | - | - | - | 24 |
| | PL | 1,2,3 | 0.0 | 0.0 | - | - | - | - | - | - | - | - | - | 25 |
| | PR/BK /GR | 1 | 0.0 | 0.0 | - | - | - | - | - | - | - | - | - | 26 |
| | | 2,3 | 0.2 | 0.3 | 2.0 | 2.5 | 3.0 | 2.2 | 2.7 | 3.2 | 2.4 | 2.9 | 3.4 | 27 |
| A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |

From the example above and assuming 500 gpd wastewater volume, the infiltration component is 125 ft long determined by dividing the daily wastewater volume by the hydraulic linear loading rate. For septic tank effluent, BOD >30 mg/L , the infiltration component width is 6.6 ft. This width would be acceptable hydraulically but may not account for the oxygen demand. Supply of oxygen to infiltration systems through soil is discussed in a paper by Erickson and Tyler, 2000 in this book. For wastewater of BOD <30 mg/L, system width is 5.0 ft. Note that changing wastewater quality only influences system width.

The table is direct and easy to use, however, the values are estimates and need field confirmation. In particular, it is possible that the hydraulic linear loading rates are too high for the slow rates and too low for the high rates. Field testing has begun in Lake County, Ohio.

## LAKE COUNTY, OHIO

Lake County, Ohio is located on the shores of Lake Erie just east of Cleveland. The population is approximately 225,000 and about 6% of the residents are served by household sewage treatment systems (HSTS). During the last twelve years, there has been a steady increase in residential development in the unsewered areas of Lake County. This development is occurring predominately where soils are rated as having severe limitations for on-site sewage treatment systems (Ritchie and Reeder, 1991). These limitations include slow permeability of soils, shallow seasonal and perched ground water tables, shallow bedrock and difficult topography.

### Soils and Landscapes

Four general soil regions exist in Lake County: soils on the lake plain and offshore bars, soils on beach ridges/offshore bars, soils on till plains and soils on flood plains/marshes. Sandy soils, some of which are deep and well drained and others with shallow seasonal ground water tables, lie north of State Route (SR) 84 which follows a glacial beach ridge.

South of SR 84, soils are silt and silty clay loams over shallow, slowly permeable horizons and bedrock. For example, the Mahoning Soil Series consists of deep, somewhat poorly drained, slowly or very slowly permeable soils on glacial till plains with seasonal ground water between 6-18 inches. Shallow shale bedrock at 30 to 40 in. below the ground surface is also common. Other soil series, with somewhat similar morphology, have the same general characteristics. Much of the new residential construction is located in these soils.

Lake County typically has warm summers and cold winters with heavy snowfall. Precipitation and snowmelt waters frequently saturate soil to near the surface. Much of this water moves horizontally down slope to lower positions in the landscape. Frequently, the soil at lower landscape positions saturates and water comes to the ground surface.

### Experience with Treatment Systems

Lake County has utilized relatively shallow trenches in conjunction with a perimeter or curtain drains for on-site systems in silt loam soils. The trenches were filled with a layer of gravel covered by coarse sand and then topsoil to the ground surface. Increased resident complaints concerning the function of newer systems prompted the Lake County, Ohio, Health District staff to conduct a survey to determine the effectiveness of the trench systems used since the late 1970's. Beginning in 1997, the staff surveyed 199 HSTS or 11.8% of HSTS installed in silt loam soils during the period of 1988-1996.

For purposes of the survey, a malfunction was defined as sewage effluent ponding at the ground surface or overflowing distribution boxes. Key parameters considered included: soil type, slope, wet weather installation, age, graveless vs conventional trench, pretreatment, and water consumption when obtainable. The overall failure rate of systems surveyed was 17%. There was a statistically significant correlation between failure rate and water consumption during seasonally wet times. The staff also conducted a literature review with respect to loading rates. The staff conducted a second phase of their survey that included reinspection of the systems previously found to be malfunctioning and 40 new systems in use for only one year. This portion of the survey included recording of a more detailed description of system failure including observing effluent levels in distribution boxes.

The second phase of the survey revealed that although the overall failure rate was 17%, one-year-old systems were failing at 35%. Failure rates of systems in Platea, Darian, and Mahoning soils were failing at rates of 61%, 66% and 37% respectively. These soils are characterized by silt loam surface horizons over slowly permeable subsurface horizons. It is important to note that these three soil types are predominant in the newly developing areas of the county. The unacceptable failure rates indicated that loading rates of the conventional Lake County HSTS were too high. The design does not effectively utilize the most permeable upper soil horizons and the nature of the installation process causes excessive damage to the soil structure. After additional study, it became evident that perimeter drains did not effectively lower the seasonal water table to any substantial degree.

## PRACTICAL APPLICATION OF THE LOADING RATE TABLE

The Health District developed a HSTS improvement plan. The ultimate goal of the plan is to allow residential construction in unsewered areas that is protective of public health and the environment while providing a reliable HSTS to the consumer. The first steps included contracting with consultants to identify potential alternative system designs for use in the most severe soils. The successful but limited use of the Wisconsin Mound on sites with very shallow bedrock (28 installed since 1989) prompted the expanded design of a “Lake County Mound”. The expanded mound was designed with basal loading rates based on soil characteristics. An improved site evaluation process was developed that included site specific soil evaluation prepared by a soil scientist in addition to considering the most desirable landscape position for the system. The method of establishing loading rates based on soil characteristics was expanded further by adding wastewater quality and slope of the site as a consideration.

The soil evaluation is utilized to determine soil characteristics for establishing the basal and linear loading rates from Table 1. In addition, the depth of the limiting layer is determined as well as the isolation distance (vertical separation) from the design infiltration depth to the limiting layer. A limiting layer is a horizon with seasonal or permanent saturation, bedrock or a slowly permeable soil. In Lake County, a slowly permeable soil has a basal loading rate from Table 1 of $<0.2 gal/ft^2$./day). The key design information such as depth to the limiting condition, design infiltration depth, land slope, linear and basal loading rates and system options are recorded in a design summary form.

In order to properly utilize the loading rate table, certain assumptions must be established. These assumptions include a minimum design infiltration depth to a limiting condition, desired wastewater quality based on the thickness of the treatment layer, and code required isolation distances to limiting conditions. A system option scheme was then developed taking the limiting conditions and wastewater quality requirements into consideration. System options range from standard trenches, mounds, subsurface and at-grade drip distribution and drip mounds. The intent is to establish design criteria and performance standards that designers can use to determine system options best suited for the site. This process will enable the Health District to diverge from the prescriptive regulatory approach to wastewater treatment design. It is important to note that extensive training for staff, system designers, installers and to a lesser degree, the soil scientists was necessary for the success of this process.

### Establishing an Experimental Household Sewage Treatment System Program

After extensive research on drip distribution and expert consultation, the Health District facilitated the installation of four experimental drip distribution systems in the fall of 1998. The Health District solicited participants by mail that had homes already in progress. Prospective homeowners and builders were educated on the fundamentals of drip distribution. Participants were required to sign an acknowledgment summarizing the experimental nature of the system and operation and maintenance requirements. The Health District provided the soil scientist reports, the drip system designs prepared by experts in the area of soil science and on-site wastewater design, a monetary contribution toward the system installation, and rigorous monitoring of system operation.

The Health District obtained approval from the Ohio Department of Health for experimental system installations of drip distribution and the “Lake County Mound”. The drip systems have been monitored extensively for the following: system and soil temperatures through two winter seasons, effluent quality of the treatment components, water consumption, and peak and high water events. Results of the monitoring have proved useful in the development of drip design and installation criteria and loading rate determination.

## Preliminary Assessment of Experimental System Function

One of the primary concerns of the Health District staff was whether a shallow drip distribution installation would freeze during a typical northeastern Ohio winter. Three drip systems were installed at six to eight inches below grade. Thermocouples were installed in areas around the tubing and outside the system. Portions of the tubing were left with only native soil cover and the remainder of the zones were mulched with wood chips. The first winter was relatively mild with ground temperatures never reaching 32°F. During the winter of 1999-2000 however, the ground temperatures fell to 29°F for a brief period. A small area around the tubing was exposed by hand excavating to reveal that although the ground temperatures fell below 32°F, the tubing did not freeze and the system continued to dose as designed.

As mentioned above, three of the drip systems were shallow subsurface installations in silt loam soils with seasonally high water tables with pretreatment via septic tanks and recirculating pea gravel filters. The fourth system is a low profile drip mound on a silt loam soil with shallow sandstone bedrock. After some initial mechanical and operational difficulties (pump and float problems), the systems have been functioning as designed. Sewage effluent has not surfaced on the ground, even during seasonally wet periods. Further monitoring and additional effluent sampling is planned for the near future.

## SUMMARY AND CONCLUSIONS

Estimates of wastewater loading rates can be made based on soil and site characteristics described by soil scientists and other field professionals. The loading rate estimates follow the logic of water movement in soil but the values are estimates. Field testing of the concepts of the table has been applied to systems in Lake County, Ohio. These systems have been successful. As Lake County continues with the HSTS improvement plan, additional systems will be tested using the values and concepts in the loading rate table.

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